FUN3D Solutions for Nose Landing Gear

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Outline

- Objectives
- Numerical Method
- Configuration and Flow Conditions
- Grids
- Results
- Computational Resources
- Observations

Objectives

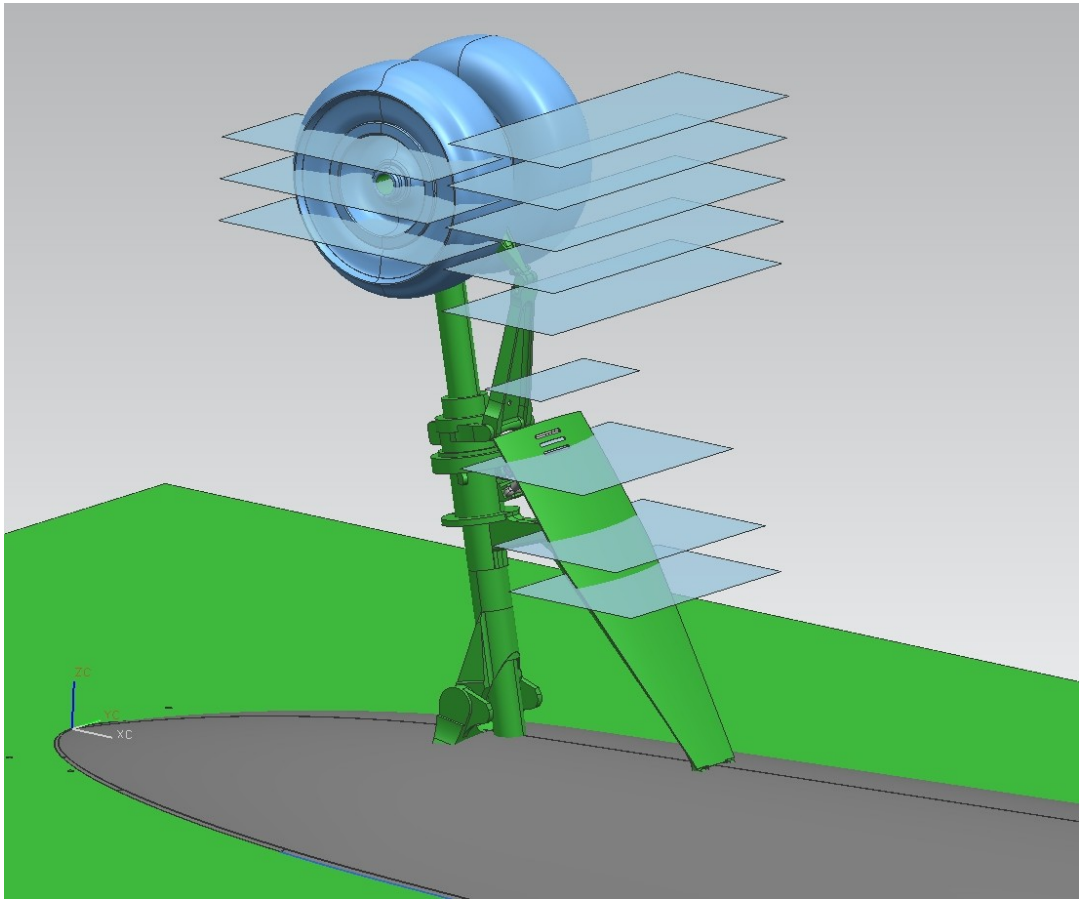
- Assess the applicability of an unstructured grid flow solver FUN3D for Nose Landing Gear configuration
- Examine grid and turbulence modeling sensitivity

Numerical Method

- Equations solved
  - Unsteady Reynolds-averaged Navier-Stokes (URANS) equations Fully unstructured node-based flow solver (FUN3D)
  - Turbulence models
    - Hybrid RANS/LES model (Ref. Lynch et al. AIAA Paper 2008-3854)
    - Modified Delayed Detached Eddy Simulation (MDDES) model (Ref. Vatsa and Lockard AIAA Paper 2010-4001)
- Spatial and temporal discretizations
  - Roe's flux-difference splitting scheme without flux limiter
  - Optimized second-order backward difference (BDF2OPT) scheme for temporal discretization: Dual-time stepping with 15 subiterations
- Boundary Conditions
  - Constant temperature, no-slip floor & gear
  - Inviscid side walls & ceiling
  - subsonic inflow/outflow for inlet and exit planes
    - Outlet pressure specified
    - Inlet total pressure and temperature specified

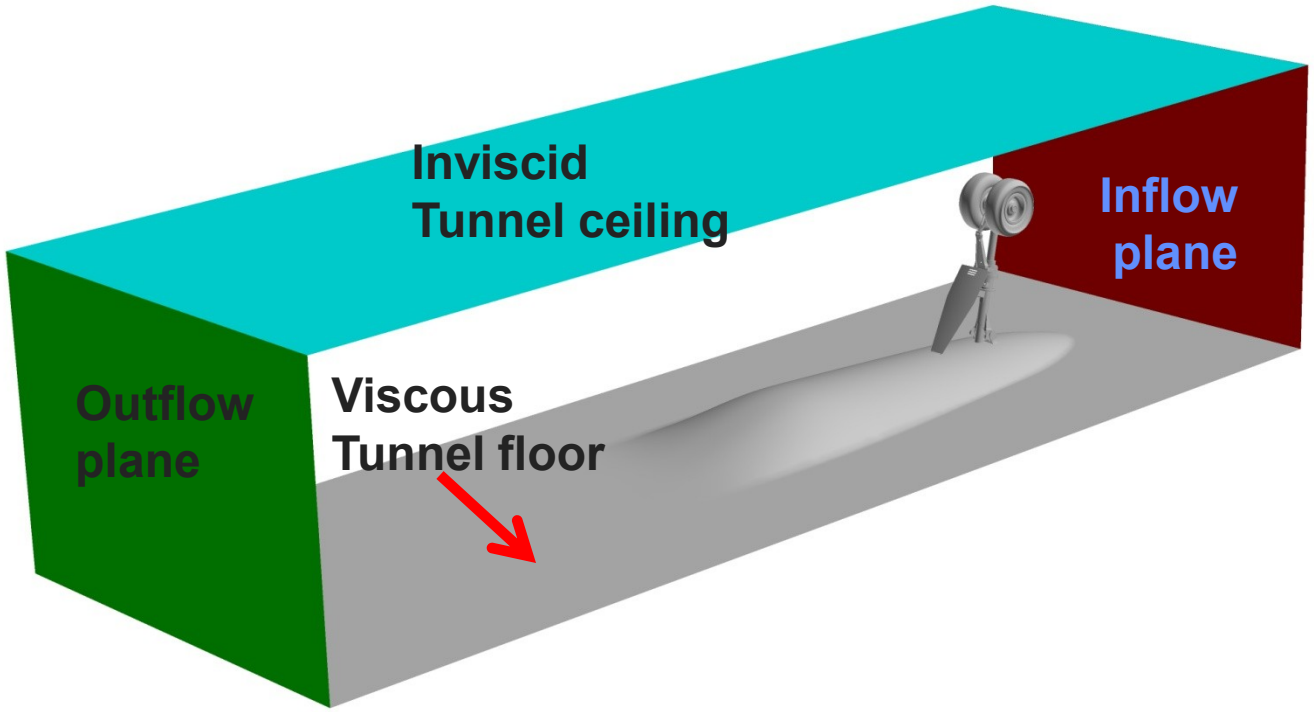
Configuration and Flow Conditions

- Re = 73,000 based on post diameter
  - Flow code run in fully turbulent mode
- M = 0.166



Computational grids

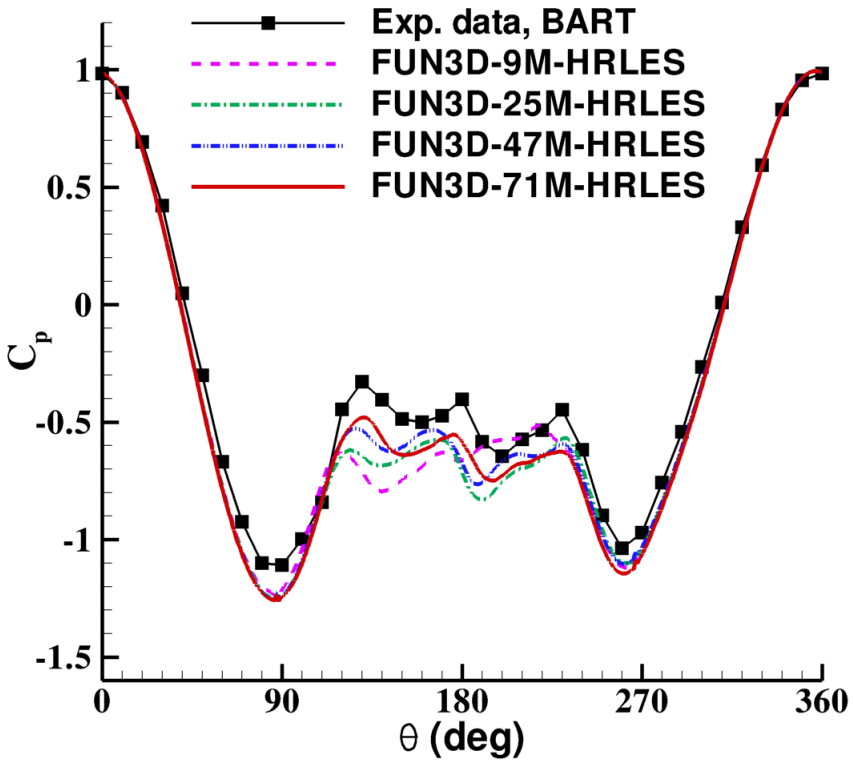
- Unstructured, mixed-element grids using VGRID
- Sequence of 3 successively refined grids: 9, 25 and 71 million nodes
- Locally enriched 47 million node grid



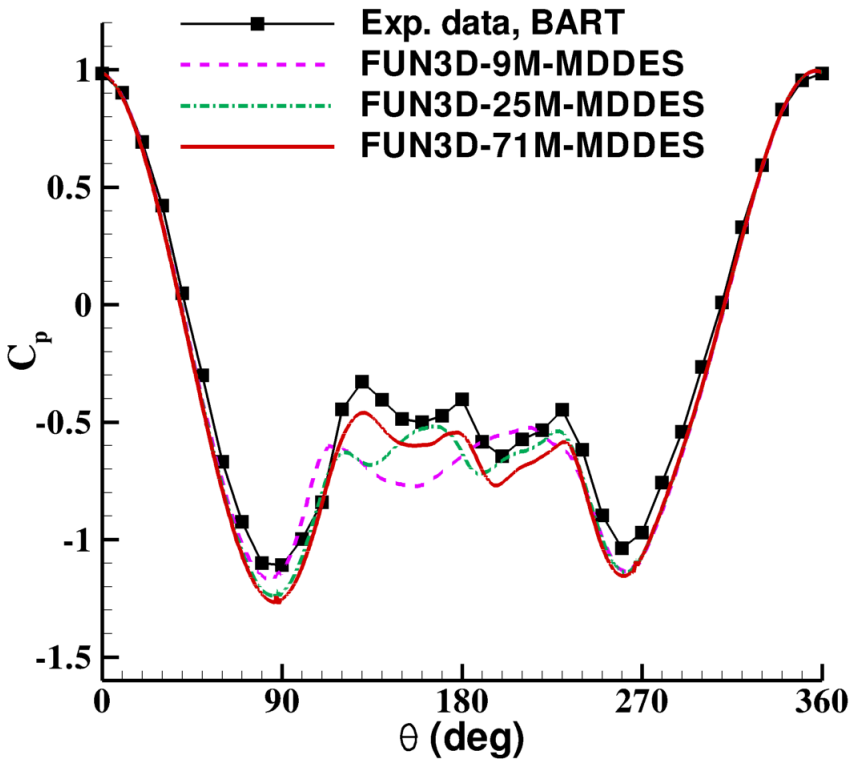
Results

- Time step
  - 4.92×10^{-6} seconds
- Number of time steps run
  - Total : minimum of 80,000 time steps
  - Sampling : Minimum of 50,000 time steps
- Convergence information
  - Cp and Cp_{rms} checked after every 10,000 time steps

Surface Pressure comparisons (starboard wheel)

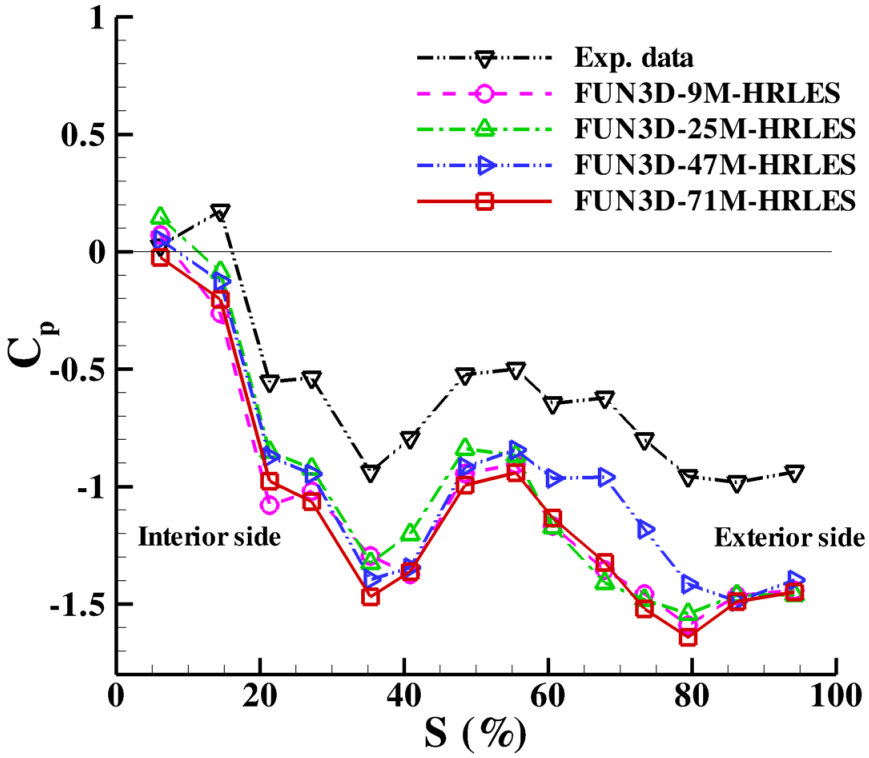


HRLES Model

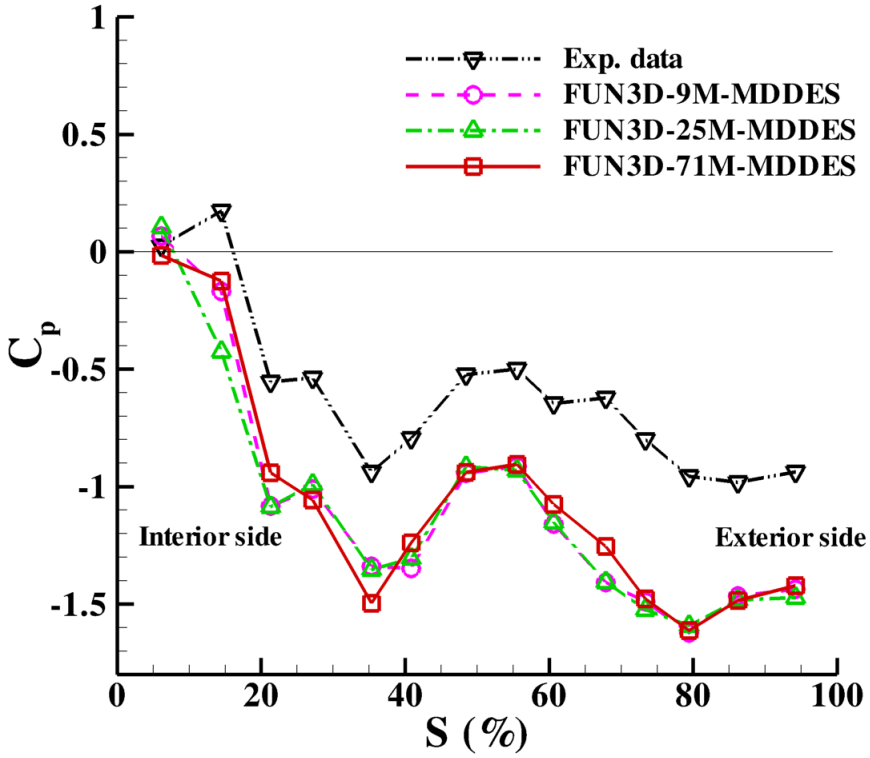


MDDES Model

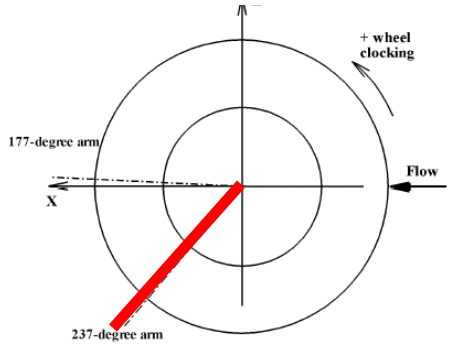
Surface Pressure comparisons
(port wheel transverse cut at 237º)



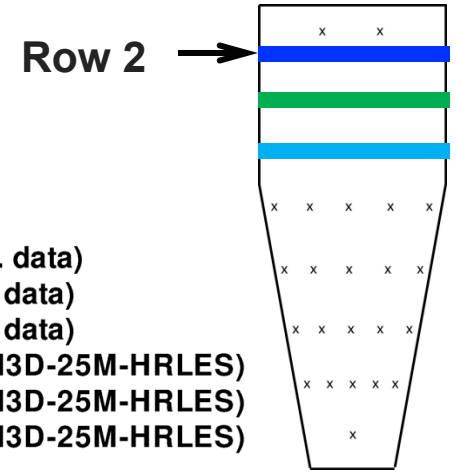
HRLES model

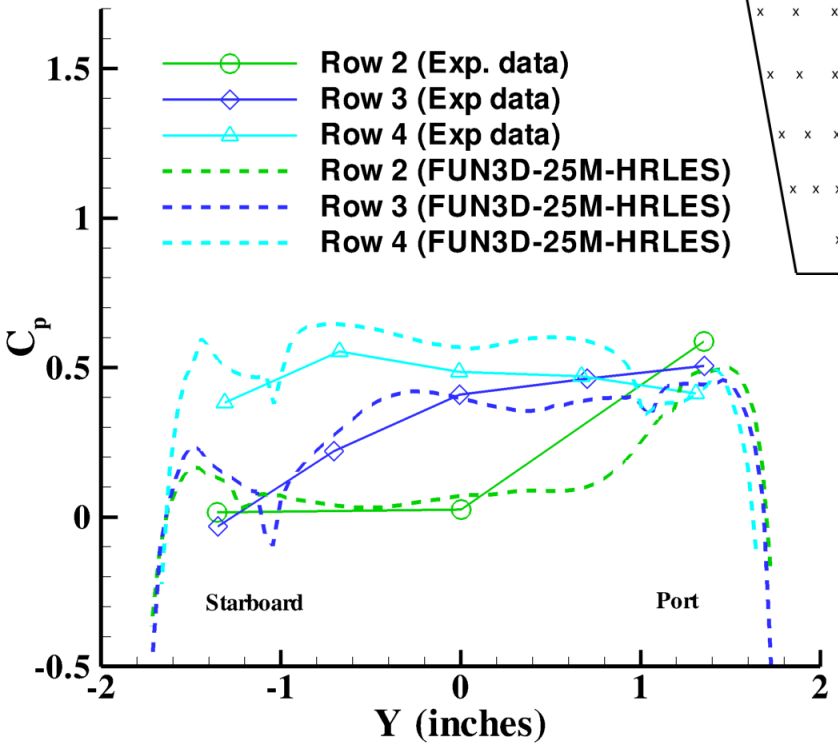


MDDES model

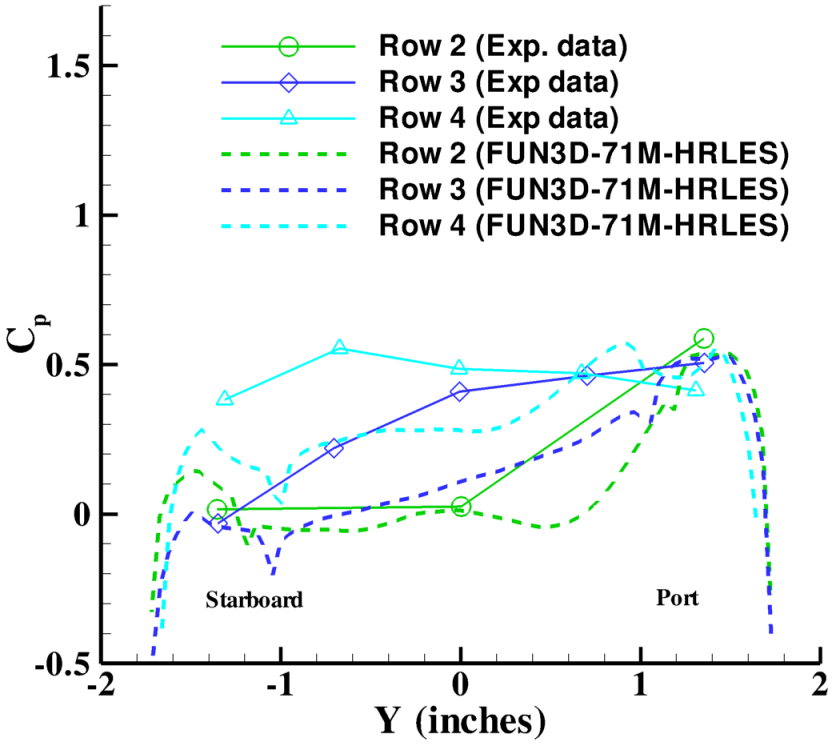


Surface Pressure comparisons at door (Rows 2-4)



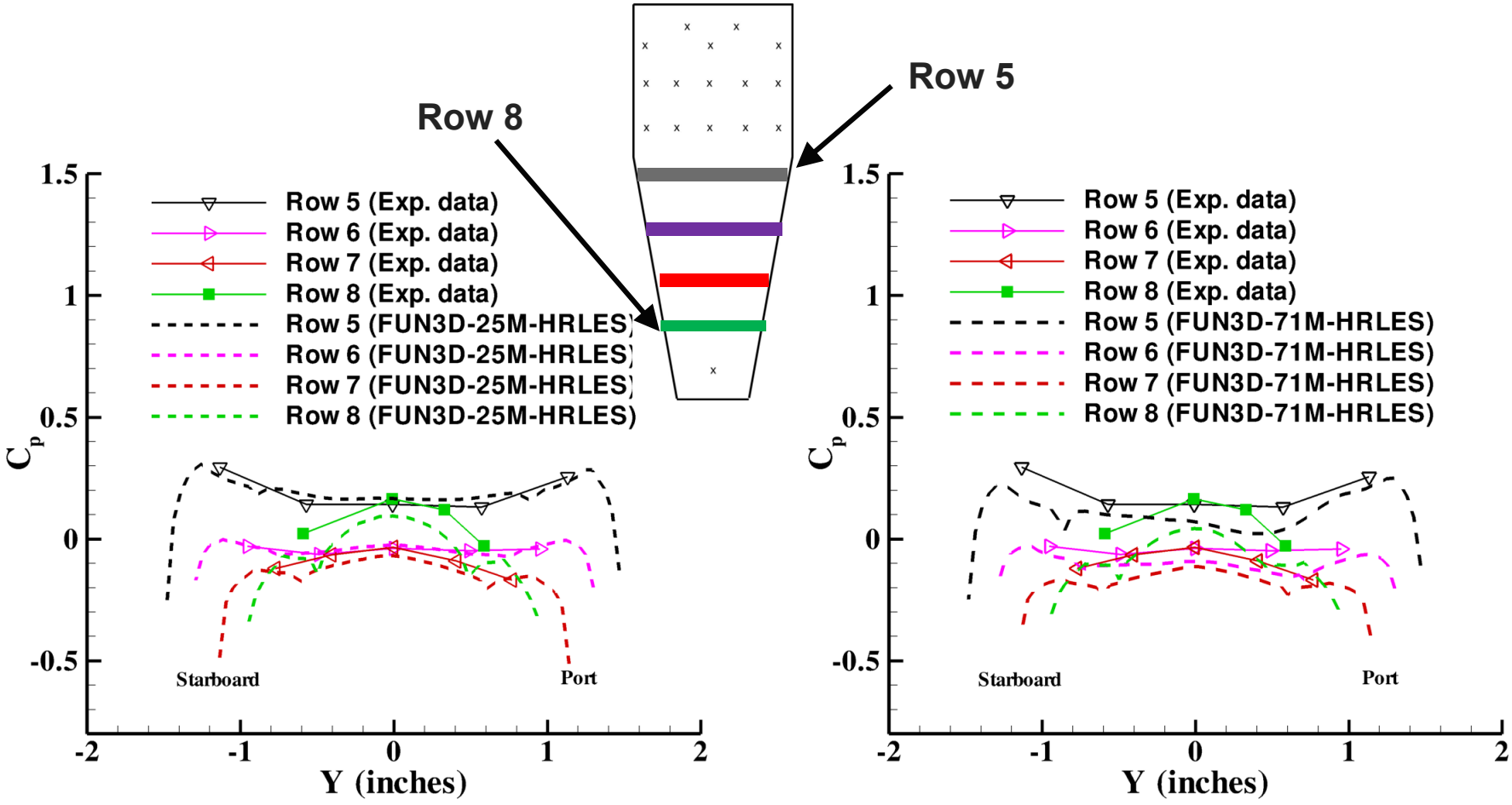


FUN3D-25M-HRLES



FUN3D-71M-HRLES

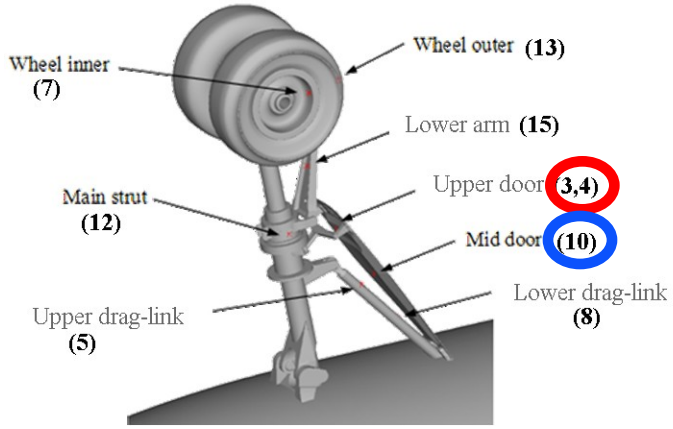
Surface Pressure comparisons at door (Rows-5-8)

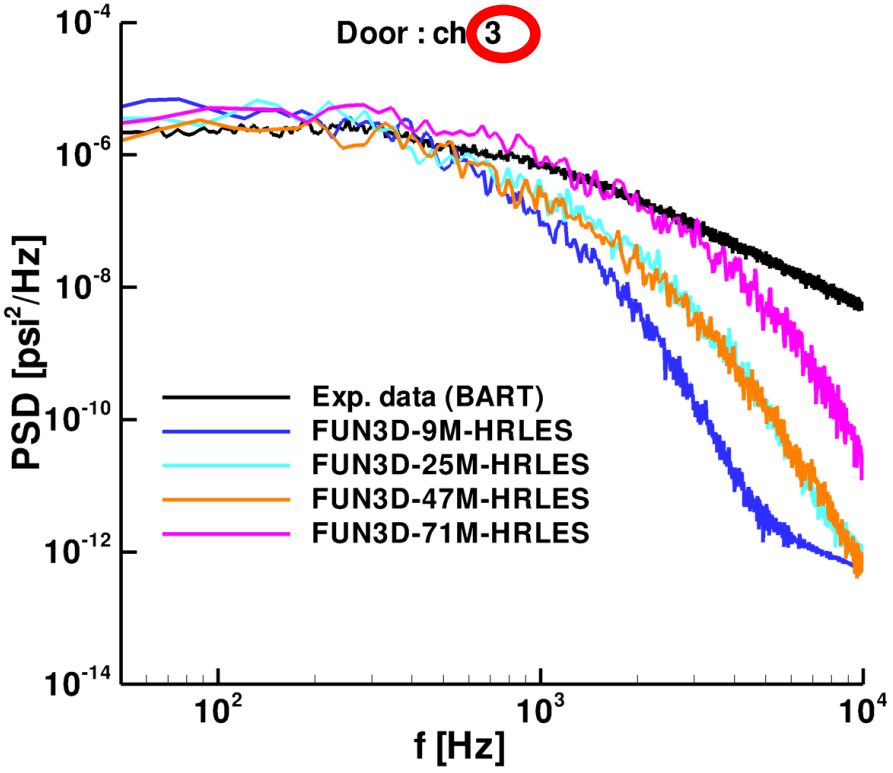


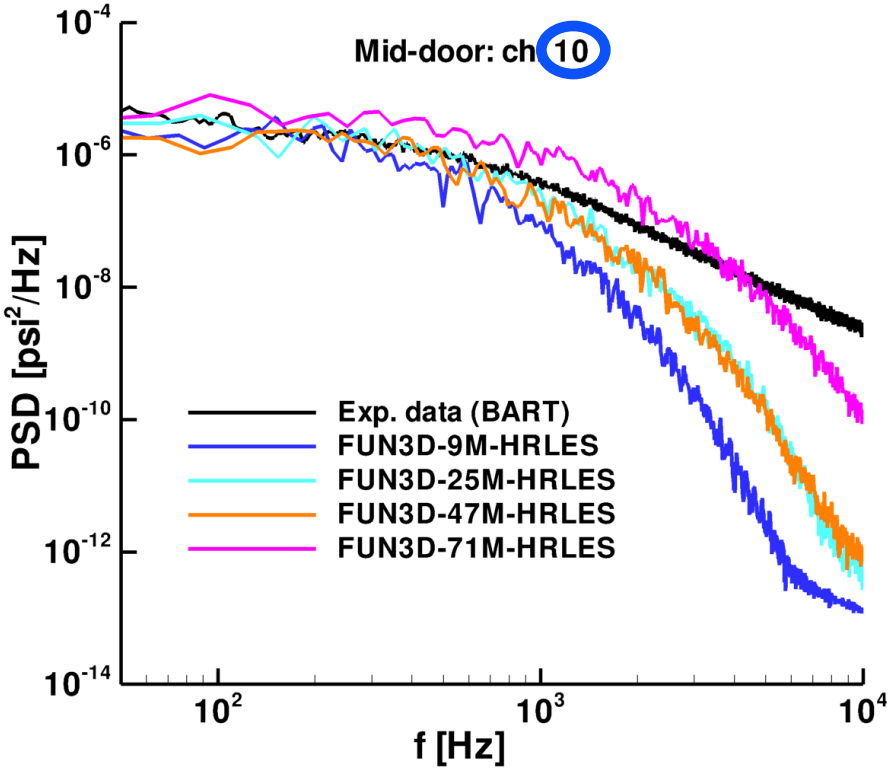
FUN3D-25M-HRLES

FUN3D-71M-HRLES

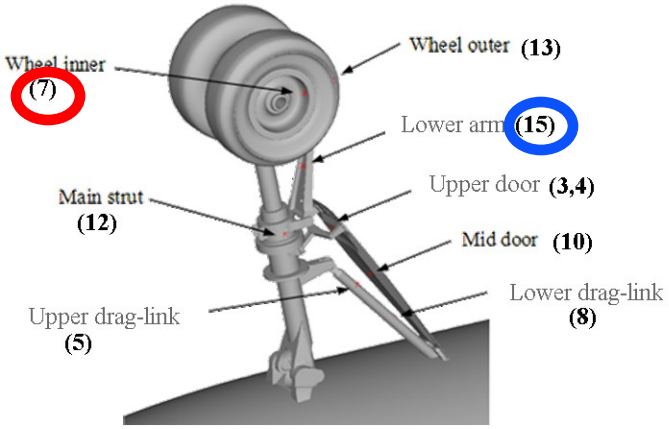
Power Spectral Density Comparisons

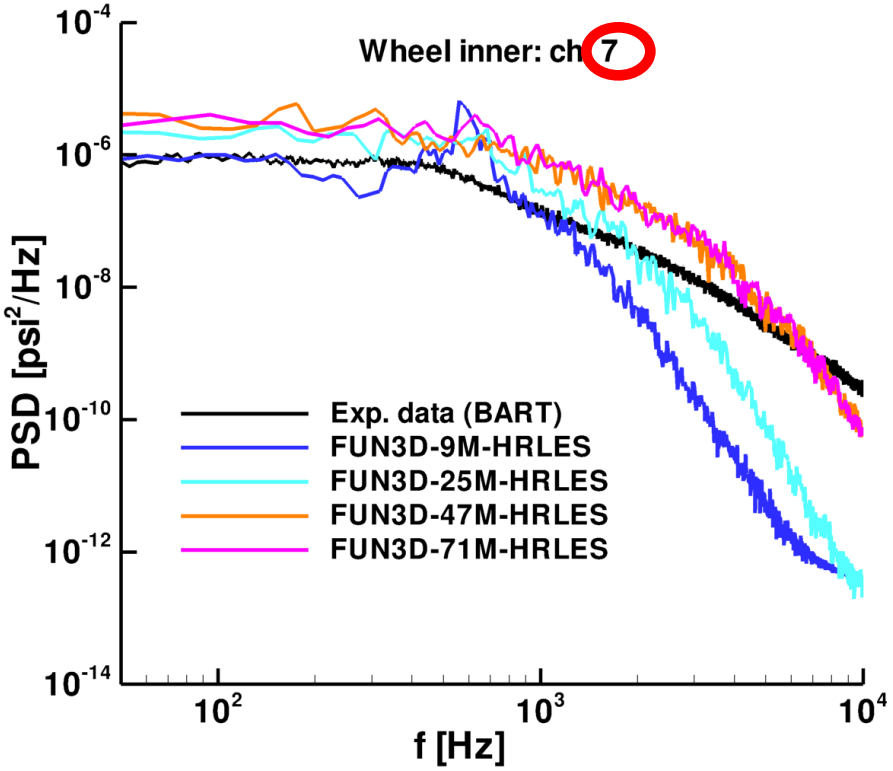


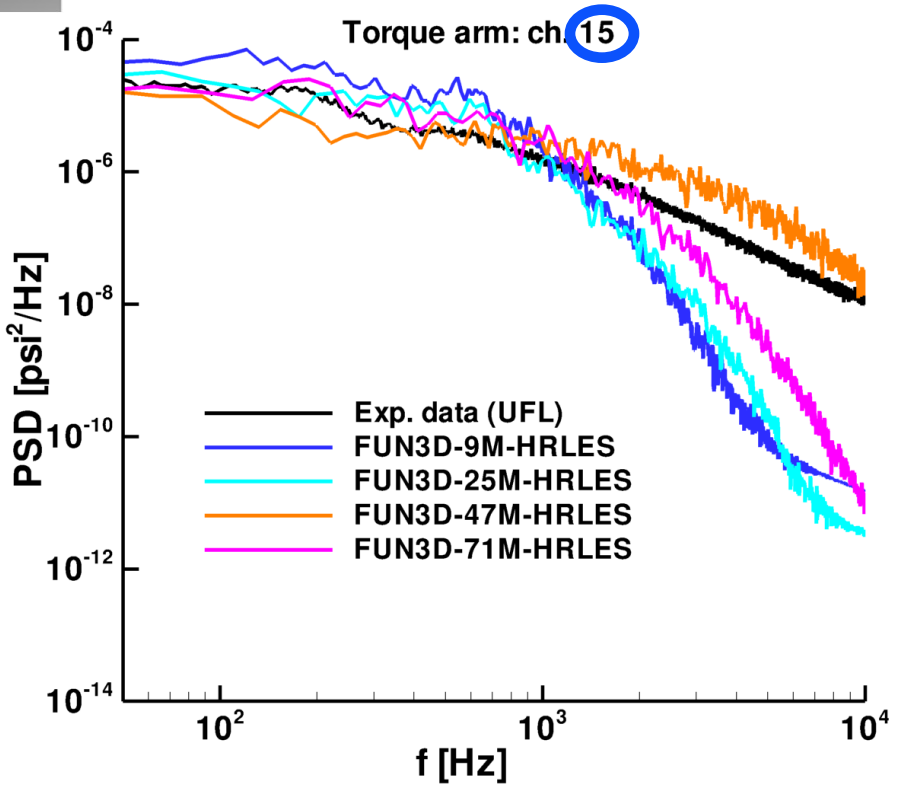




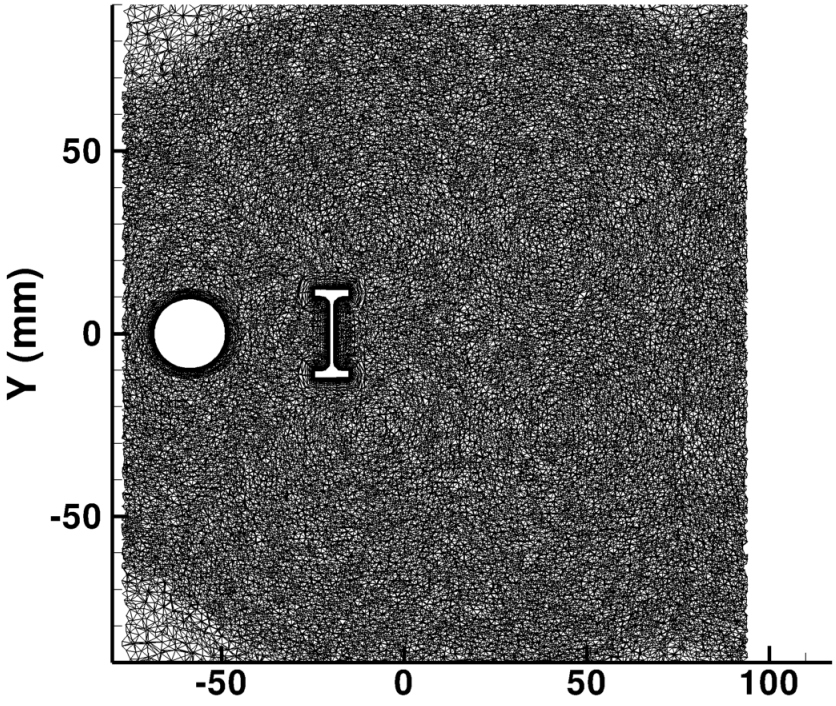
Power Spectral Density Comparisons … (2)



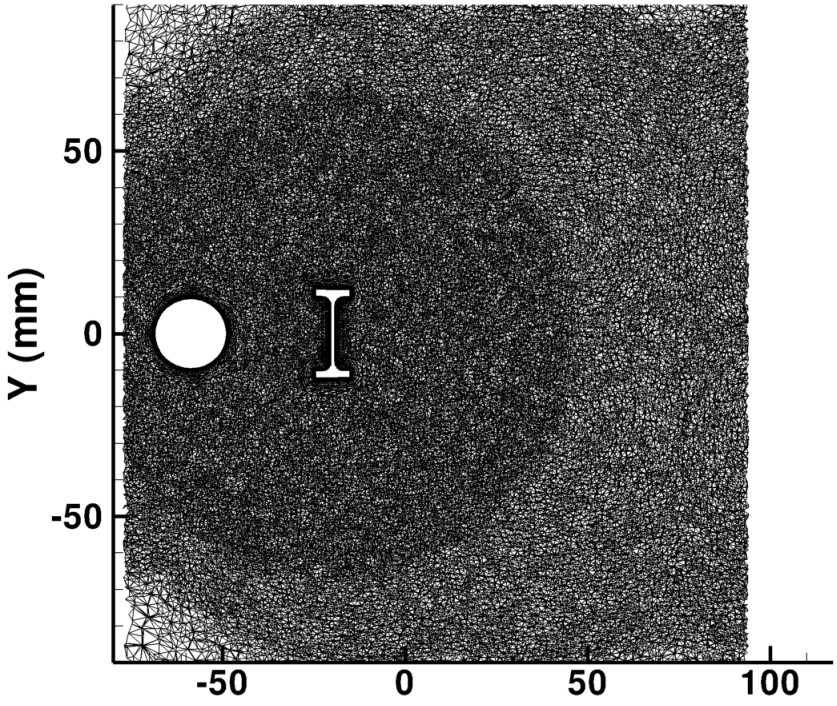




Partial view of grid near torque-arm

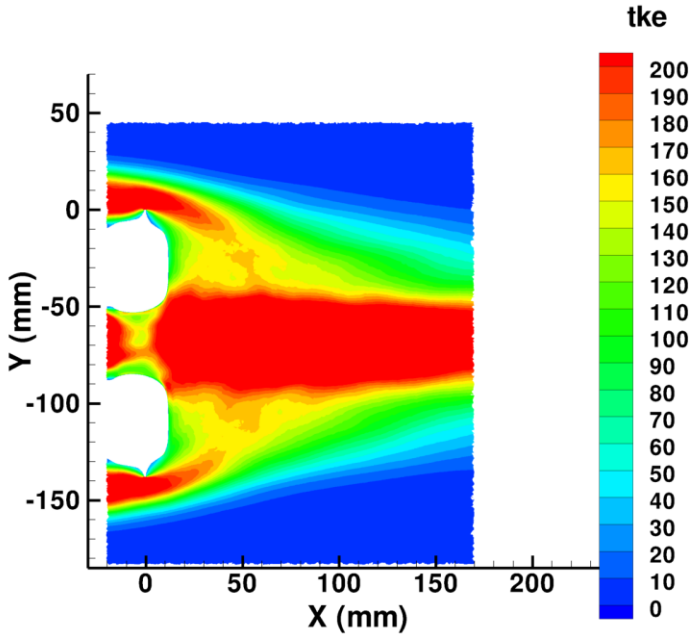


25 M node grid

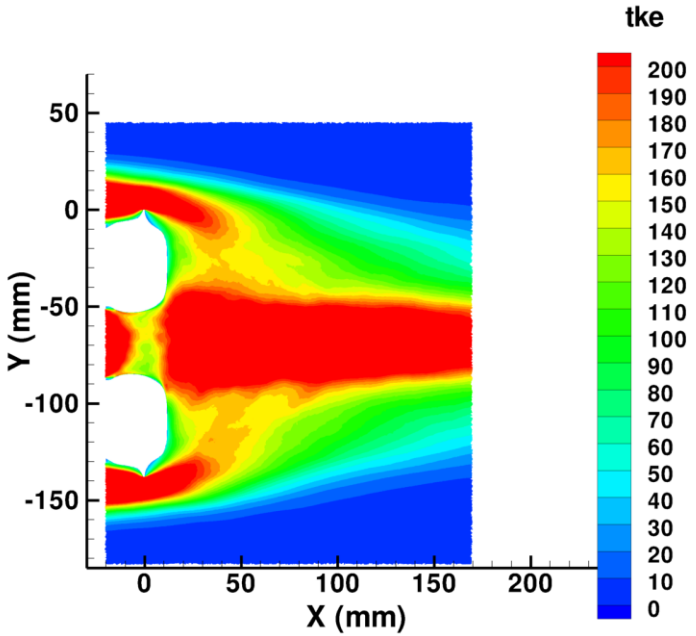


47 M node grid

2-D Turbulence Kinetic Energy at wheel wake centerline

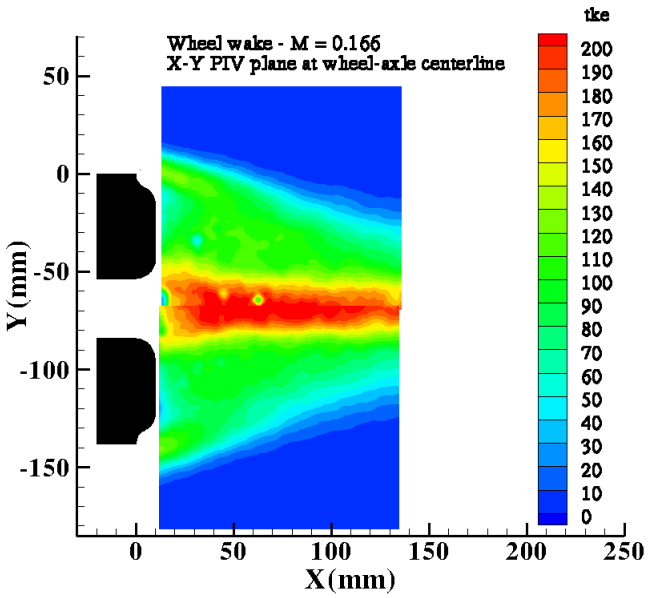


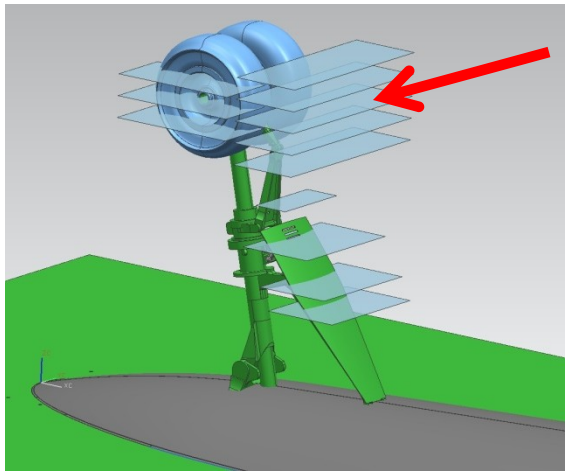
FUN3D-25M-HRLES



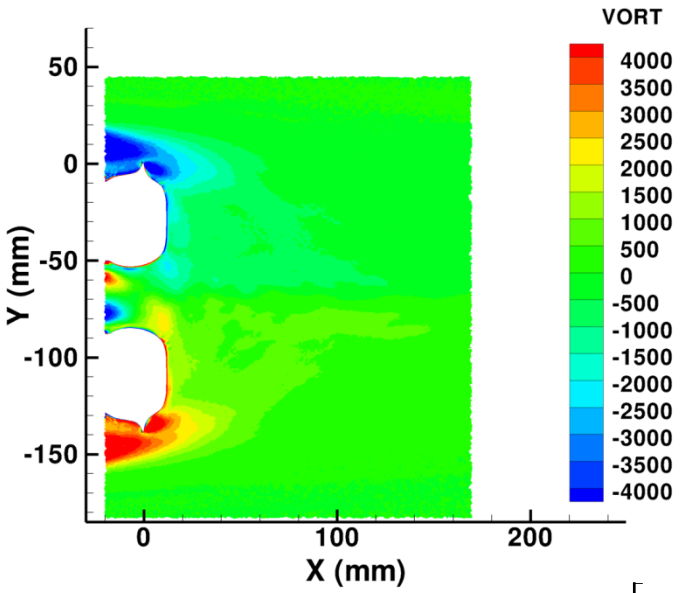
FUN3D-71M-HRLES

Exp. PIV data





Spanwise vorticity at wheel wake centerline



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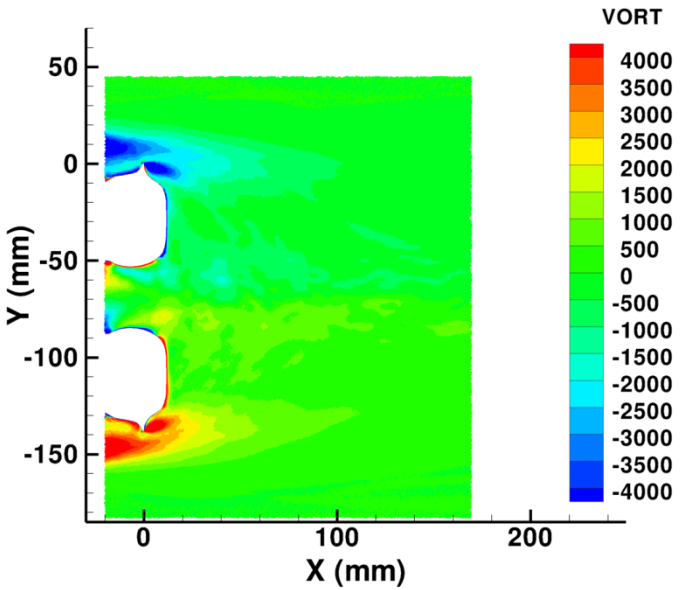

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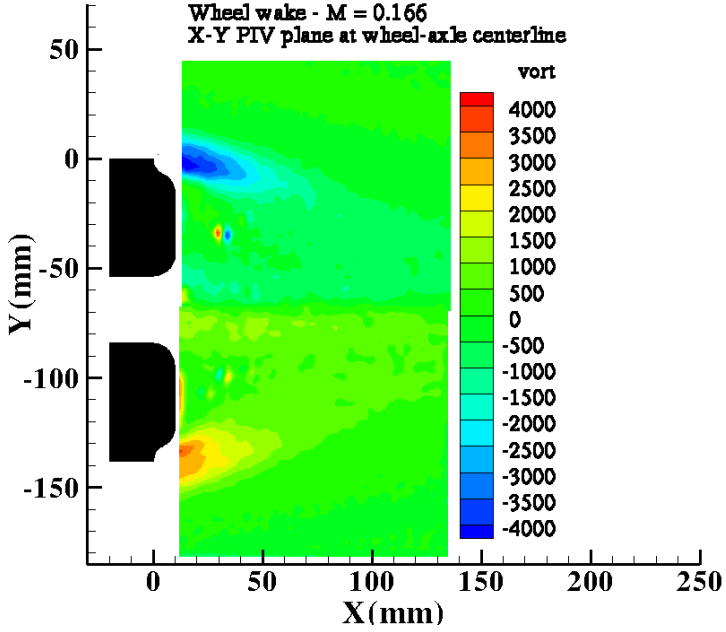
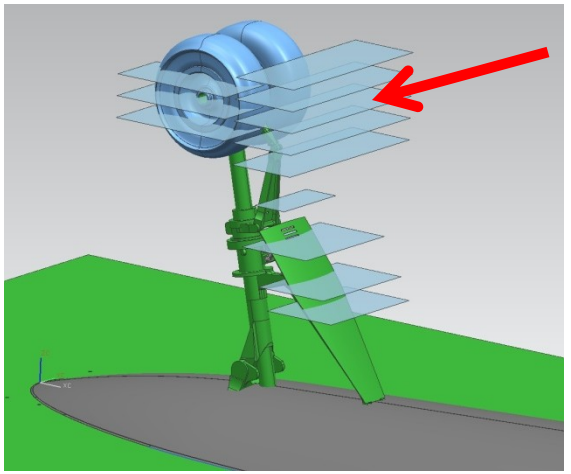
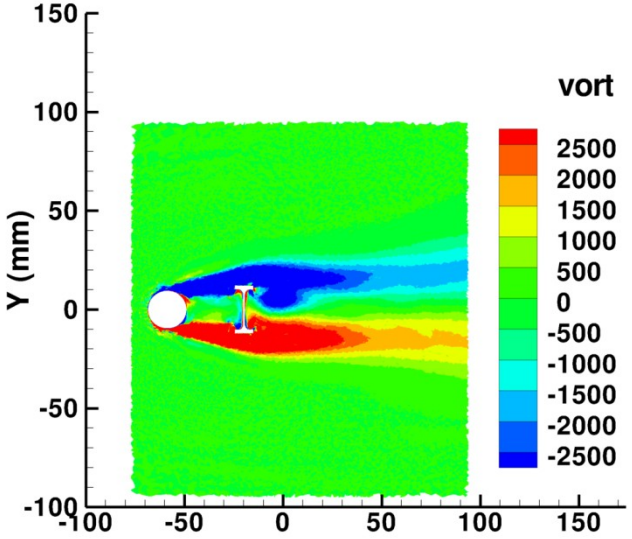




Spanwise vorticity at torque arm wake



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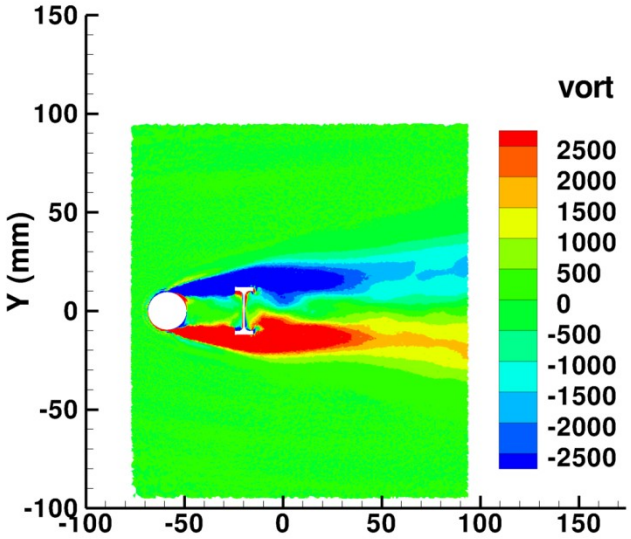

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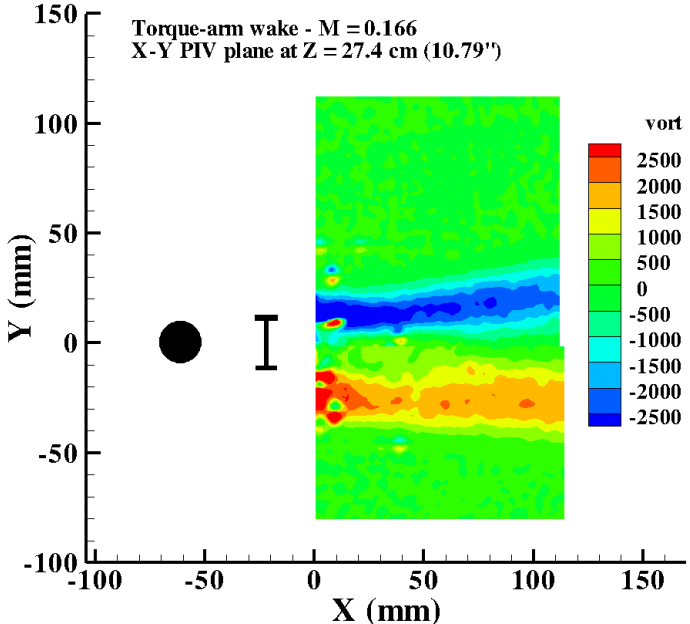
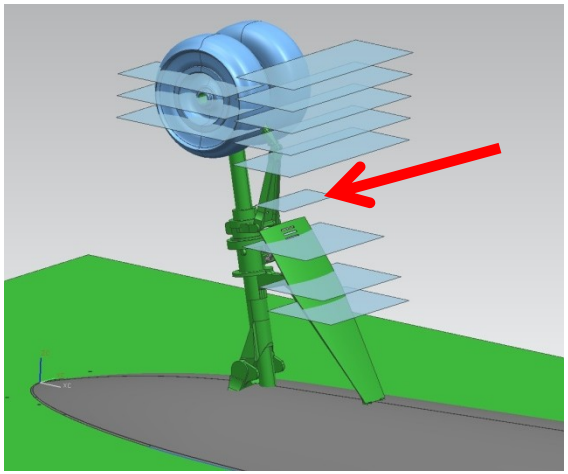
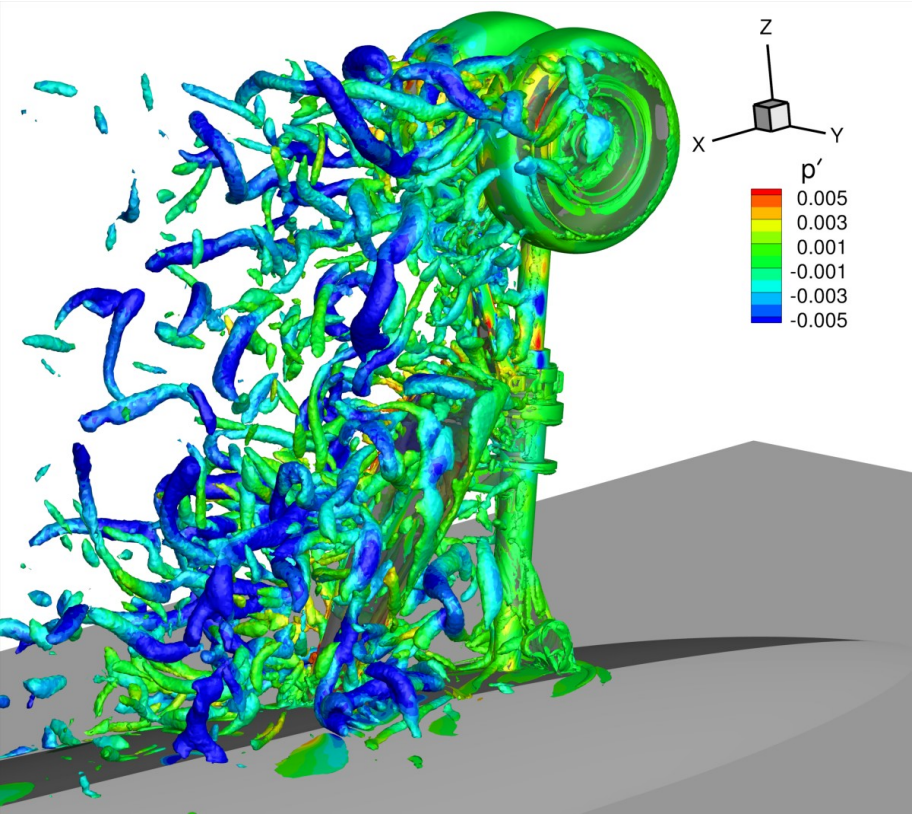


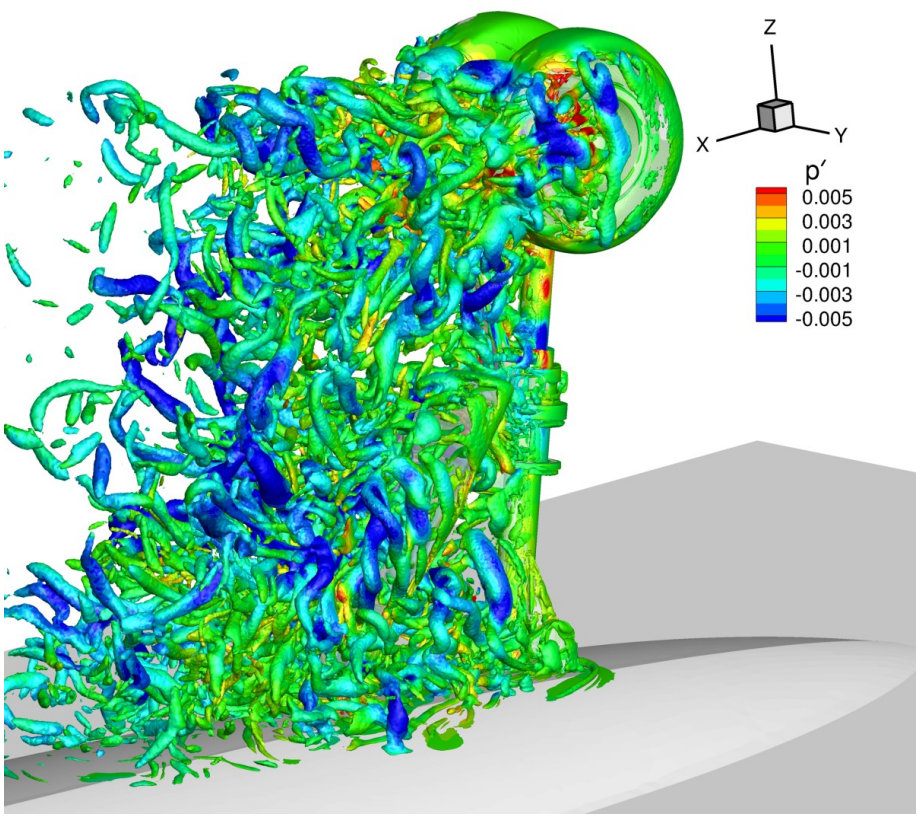


Iso-surfaces of Q-criterion

- Colored with perturbation pressure



FUN3D-9M-HRLES



FUN3D-25M-HRLES

Computational Resources

- Computer hardware
  - CPU: NAS Pleiades, 2 quad-core Xeon E5472 Harpertown cpu's/node, 1GB memory/core
  - Interconnect:Infiniband
- Resources (for 25 M nodes, HRLES case)
  - CPU (or wall clock) Time / time step : 33.8 secs. using 960 cores
    - Minimum of 80,000 time steps in simulation
    - Minimum of 50,000 time-steps for data sampling

Observations

- What did you learn?
  - Computational challenges
    - Significant computational effort for statistically meaningful results
    - Constructing suitable grids very challenging
  - New insights into the physics
    - Complex flow physics, difficult to simulate with fixed (non-adapting)grids
      - Manual, local refinement effective but tedious
    - Tunnel inflow/outflow b.c.'s could influence computations
    - Transition difficult to simulate, could impact flow on smaller components
  - Assessment of state-of-the-art based on your simulation for the problem category of interest
    - Encouraging results, solutions capture salient flow features
    - Uncertainty due to grids, transition and turbulence modeling
  - Recommendations for follow-on efforts
    - Need test data to quantify Reynolds number sensitivity
    - Need systematic grid refinement/adaptation studies, better turbulence/transition modeling